

CHAPTER 2

OVERVIEW OF PROFESSIONAL FABRICARE TECHNOLOGIES

This chapter provides an overview of the professional fabricare technologies covered in the Cleaner Technologies Substitutes Assessment (CTSA). The technologies evaluated in the CTSA are listed in Section 2.1.1. Section 2.2 gives background information on clothes cleaning. Section 2.3 describes the clothes cleaning processes equipment. Section 2.4 gives the chemical characterization of the technologies evaluated in the CTSA. The chapter closes with Section 2.5, a market profile of the commercial fabricare industry.

CHAPTER CONTENTS

2.1	Technologies Evaluated in the CTSA
2.2	Clothes Cleaning Process
2.3	Process Equipment Descriptions
2.4	Chemical Characterization of Technologies
2.5	Commercial Fabricare Industry Market Profile

2.1 TECHNOLOGIES EVALUATED IN THE CTSA

Several technology alternatives are available for clothes cleaning, and can generally be categorized into dry and wetcleaning alternatives. These categories are distinguished by the primary type of solvent used. Drycleaning refers to processes that use predominately non-aqueous solvents. The term “drycleaning” is a misnomer because clothes are actually immersed in a liquid solvent, and some water may be included in the solution. Wetcleaning processes are those that use predominately water as a solvent.

Drycleaning chemicals are chosen for their ability to dissolve organic materials that soil fabrics. Two drycleaning solvents currently dominate the market in the United States, perchloroethylene (PCE) and hydrocarbon solvents, which include Stoddard solvent, 140°F solvent and DF-2000. These are generally referred to as hydrocarbon (HC) solvents throughout the document. The CTSA discusses the risks associated with these solvents. PCE drycleaning is prevalent in the industry, and there are numerous machine configurations that can affect costs, risks, and other considerations. The CTSA examines several alternative modifications and machine configurations for PCE and HC cleaning, primarily for the difference in releases and costs.

In addition to drycleaning, “wet” or aqueous-based cleaning is a possible process substitute that may accomplish many of the same functions as drycleaning. The term “wet” refers to the use of a quantity of water during the process, but garments may never be fully immersed or saturated with water in some processes. Certain aqueous-based processes can be used on many garments, and are potential substitutes for drycleaning. Others are designed only for certain types of garments, and may become an alternative for a part of the total clothes cleaning volume.

USEPA originally sponsored testing of an approach to wetcleaning called “multiprocess wetcleaning”; however, this technique is no longer practiced in the commercial field. It has been

replaced by a variety of combinations of machine wetcleaning and, therefore, machine wetcleaning is included in the CTSA. For this process, the CTSA discusses the risks associated with sample detergents.

2.2 CLOTHES CLEANING PROCESS

Clothes go through several steps at professional fabricare facilities. The following steps generally apply to cleaners using dry or wetcleaning processes. However, steps and procedures may vary considerably depending upon the facility, and there are some distinctions between dry and wetcleaning processes. The professional cleaning process begins with the sorting of clothes into similar fabric weights, colors, and finishes. Clothes are examined for stains. When stains are found, spotting agents are applied to remove stains from the clothes. Clothes are then loaded into the cleaning machine (CARB, 1993; Gottlieb, 1997; NIOSH, 1997).

The clothes are washed in the machine by immersion and spin-agitation in a solvent-detergent solution. The machine then drains and spin-extracts the solution from the clothes. Cleaners occasionally add second washing and extraction steps for better cleaning (CARB, 1993). After the final solvent extraction from the clothes, the clothes are tumble-dried using heated air. The dry clothes are then removed from the cleaning machine (CARB, 1993; Gottlieb, 1997; NIOSH, 1997). The equipment used to clean clothes is discussed in Section 2.3.

After cleaning, clothes are rechecked for stains. If stains are found, spotting agents will be applied. The final major step in the clothes cleaning process is pressing. Pressing uses steam and physical pressure to remove wrinkles and reshape clothes as needed (CARB, 1993). A variety of pressing equipment is available (NIOSH, 1997). Wetcleaners who process 100% of garments may be more inclined to purchase specially-designed pressing equipment that uses tension (Gottlieb, 1997). However, pressing equipment is not covered in this CTSA.

2.3 PROCESS EQUIPMENT DESCRIPTIONS

This section describes the primary equipment used to clean garments for the technologies covered in this CTSA. This equipment and their functions affect the environmental releases, human and environmental exposures, and economic assessments within the CTSA.

The description is not a complete listing and description of all cleaning equipment but, is intended to generally cover many of the important aspects of much of the cleaning equipment.

2.3.1 Perchloroethylene Processes Equipment

PCE use in drycleaning became prevalent in the 1960s, and several of PCE's desirable characteristics have helped it to become the most common drycleaning solvent in the United States. As the use of PCE in drycleaning has proliferated, a combination of financial factors, regulations, and environmental concerns have given drycleaners incentives to reduce the loss of PCE. As a result, PCE drycleaning equipment has evolved considerably. With the variety of drycleaning equipment has come a

variety of terms to describe it. This CTSA attempts to describe the equipment using the most commonly-used terminology, although specific terms may have different meanings to various people.

The following equipment comprises most PCE drycleaning machines: rotating cylinders or drums for washing, extracting, and drying; condensers; charged and pure solvent tanks; a still; filters; a lint trap; a water separator; and solvent vapor recovery devices, including carbon adsorbers, refrigerated condensers, and/or other devices. Some facilities have other equipment. Some PCE equipment variations, features, and functions are described below. Special emphasis is given to equipment that particularly affects exposures and releases of PCE.

Machine Types

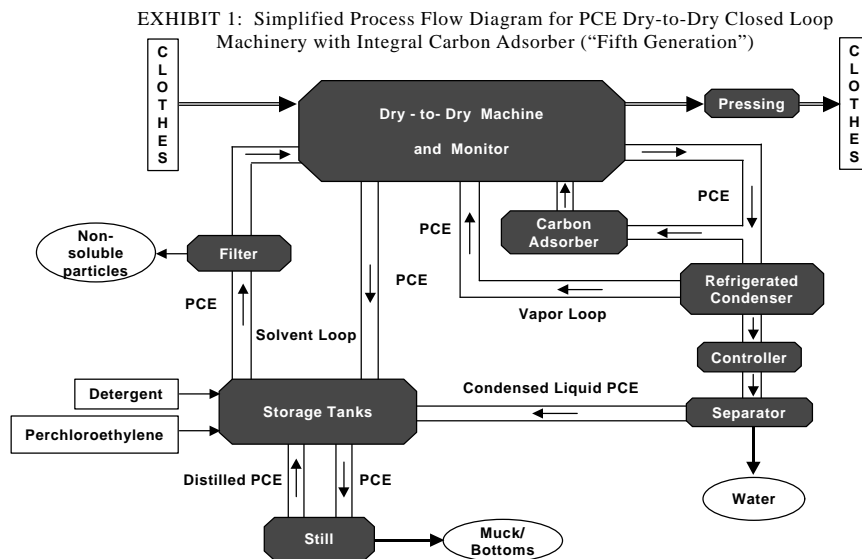
Machines used to clean garments and other articles may be classified into two types: transfer and dry-to-dry. Like home clothes washing equipment, transfer machines have a unit for washing/extracting and another unit for drying. Following PCE extraction, articles which had been immersed in PCE are transferred by a worker from the washer/extractor to the dryer, sometimes called a reclaimer. Dry-to-dry machines wash, extract, and dry the articles in the same cylinder in a single machine, so the articles enter and exit the machine dry. Transfer machines are sometimes called “first generation” machines. Dry-to-dry machines may be called “second”, “third”, “fourth”, or “fifth” “generation”, and each machine’s designation depends upon its internal PCE vapor recovery machinery. Exhibit 2-1 presents process flow diagrams for dry-to-dry and transfer machines.

Equipment for Vapor Recovery in the Machine

Vapor recovery of PCE in the drycleaning machine occurs during the drying of the articles. During the drying cycle, heated air is forced into the cylinder containing the wet articles and PCE vaporizes into the heated air. The heated air containing PCE vapor passes through a lint bag and enters a condenser. The condenser cools the air and condenses some of the PCE, which is recovered. The air from the condenser is reheated and cycled back to the cylinder until the condenser no longer condenses much PCE from the heated air stream. Some machines have drying sensors, that control the drying cycle duration (CEPA, 1993).

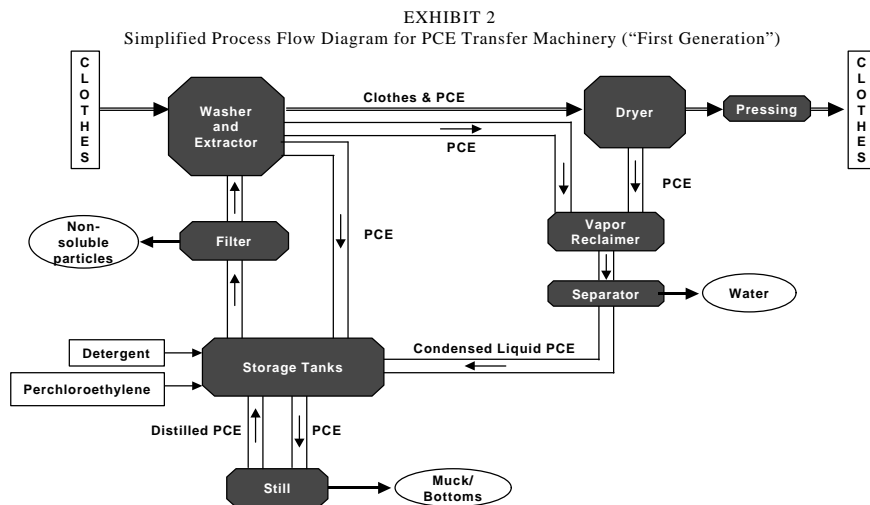
Two types of condensers are used to perform this initial PCE vapor recovery: conventional and refrigerated. Conventional condensers are usually cooled using water. This cooling water may be circulated or once-through. Circulated water would pass through a cooling circuit such as a cooling tower or a water chiller. Some conventional condensers may use air for cooling rather than water. Refrigerated condensers (RCs) usually operate at lower temperatures than conventional condensers, and the lower the condenser’s operating temperature, the more PCE the condenser will recover from the air. USEPA’s PCE drycleaning National Emission Standard for Hazardous Air Pollutants (NESHAP) requires an RC exhaust-side temperature of no more than 45°F. At the end of the cool-down cycle, conventional water-cooled condensers can reduce PCE concentrations in the cylinder to 25,000 to 75,000 parts per million (ppm), while RCs can reduce PCE concentrations in the cylinder to 2,000 to 8,600 ppm (CEPA, 1993; NIOSH, 1997).

Exhibit 2-1. Simplified Process Flow Diagram for PCE Dry-to-Dry Closed-Loop Machinery with Integral Carbon Adsorber ("Fifth Generation")^a



Source: Adapted from NIOSH, 1997.
With consultation from Hill, Jr., 1998.

Simplified Process Flow Diagram for PCE Transfer Machinery ("First Generation")



Source: Adapted from USEPA, 1991b for the U.S. Environmental Protection Agency's Office of Pollution Prevention and Toxics.
With consultation from Hill, Jr., 1998.

^a The simplified process flow diagrams in this CTSA have been developed from various sources. These diagrams may therefore have differences in appearance, components, and flows. The reader is cautioned not to interpret all these differences as having significance due to the issues presented in this CTSA. These diagrams are intended to show some of the major equipment components and flows. Some equipment components and flows may not be shown, and some facilities may have variations which are not represented on these diagrams.

Machines with conventional condensers have an aeration cycle following the drying cycle. Dry-to-dry machines with conventional condensers are sometimes called “second generation” machines. During the aeration step, fresh air is forced into the cylinder containing the clean, dry clothes to remove the odor of residual PCE from the clothes. The aeration air leaving the cylinder contains PCE and may be vented to atmosphere or may enter another vapor recovery device. When vented to the atmosphere, the aeration air is a primary source of “vented emissions” from drycleaning machines, subject to the NESHAP.

A device that can either recover PCE from vented aeration air or eliminate the aeration step from first and second generation machines is sometimes called a “primary control.” RCs and carbon adsorbers (CAs) are the most commonly used primary controls. Once the CA reaches its capacity for adsorbing PCE from the aeration stream (e.g., daily), the PCE is usually removed (desorbed) from the CA by passing steam through the CA. Steam containing PCE exits from the CA and is routed to a condenser, which liquefies the PCE and water vapors. The liquid PCE and water mixture from the condenser is routed to the water separator. The CA must dry thoroughly before it is ready for reuse.

An azeotropic device is another device for recovering PCE from aeration air. An azeotrope is a mixture of liquids with a boiling point that is lower or higher than any of its components. PCE and water can be mixed to form a low boiling azeotrope. In azeotropic devices used in PCE drycleaning, the aeration air containing PCE is bubbled through water, forming an azeotrope in the aeration air. This azeotrope condenses at a lower temperature than PCE itself would condense, so more PCE can be recovered using the azeotropic device than could be recovered without it. The aeration air circulates in the machine until the condenser can no longer recover the PCE/water azeotrope. The condensed PCE and water are routed to the water separator. Because azeotropic units are not widely used, they will not be discussed further.

Machines with RCs do not have an aeration step since they remove more PCE from the drying air than machines with conventional condensers do. The dry-to-dry machines with RCs are sometimes called “closed-loop” machines because they do not vent aeration air. Machines with RCs have a cool-down cycle following the drying cycle. Air is no longer heated, but continues to circulate between the cylinder containing the clothes and the condenser, which cools the air and recovers more PCE. At the end of the cool-down cycle, the condenser no longer recovers much PCE from the unheated air stream.

Some machines with RCs have no additional equipment for emission or exposure reduction at the end of the drying cycle although significant PCE concentrations remain in the cylinder of the machine. Other machines with RCs may have a fan that is intended to reduce worker exposures by drawing air into the cleaning cylinder when the door is opened at the end of the drying cycle. The air brought into the cylinder by this “door fan” or “OSHA fan” may be vented into the facility, outside the facility, or to a small (one- or two-pound capacity) CA. The National Institute for Occupational Safety and Health (NIOSH) has found that these small CAs are ineffective in capturing PCE unless the carbon is either changed or desorbed daily (NIOSH, 1997). The air vented from a machine’s “door fan” into the facility either directly or indirectly through a small, ineffective CA may contribute to increased PCE concentrations in the facility. The various dry-to-dry machines described in this paragraph are sometimes called “third generation” machines.

Some closed-loop dry-to-dry machines have a large, “integral” CA (usually 50- to 60-pound carbon capacity or greater [NIOSH, 1997]) that is activated at the end of the cool-down step to reduce the PCE concentration in the cylinder. These machines are sometimes called “fourth generation” machines. Air containing PCE from the cylinder passes through the CA where PCE is adsorbed to the carbon and returns to the cylinder. CAs used in this configuration are sometimes called “secondary controls.” Some fourth generation machines may have a sensor to monitor PCE concentration in the air in the cylinder and control the adsorption until a desired PCE concentration (e.g., 290 ppm) is achieved.

Some other machines have the features of the “fourth generation” machine just described and an additional door lock. This lock will not open until the PCE monitor detects the desired PCE concentration “set point” in the cylinder. Reaching this set point indicates that the PCE recovery cycle is complete. Thus, the door lock assures that the PCE recovery cycle is completed before the door may be opened. These machines are sometimes called “fifth generation” machines. The PCE adsorbed by the CAs in these fourth and fifth generation machines is removed (desorbed) from the CA by non-contact steam or electrical heating (desorption) of the CA. Most of the desorbed PCE is then recovered by the RC.

Liquid PCE Reclamation Equipment

Filtration and distillation allow drycleaners to clean and reuse PCE. Careful equipment use and on-site recovery of PCE reduces the amount of PCE lost per volume of articles and reduces the need to purchase replacement PCE. To remove insoluble materials from PCE, four primary filter types are used: cartridge, tubular, disk, and regenerative. The two most common filter types are disk (also called spin disk) filters and cartridge filters (Murphy, 1994). Polishing filters and filter additives sometimes supplement filters to improve PCE purity (CEPA, 1993).

The spin disk filter consists of fine-mesh disks in a tube. Some disk filters are made to use filter powder to aid the filtration process. Powder is not needed for powderless disk filters. For those that use powder, the powder is coated on the disks’ surfaces, and that coating is maintained by a constant flow of PCE through the filter. Powders such as diatomaceous earth (i.e., clay) and carbon are added to the PCE that passes through the outer parts of the tube and is deposited on the outer sides of the disks. During filtration, PCE contaminated with insolubles passes into the tube, depositing the insolubles on the outside of the disk. When the pressure across the disk increases to a certain level, filtration ends and the filter is spun. The insolubles (and powder, if used) spin off the disks and into the PCE, which is then sent to distillation. Powderless disk filters may require a finishing or polishing filter to remove extremely small insolubles such as dyes that pass through these filters (CEPA, 1993).

Tubular filters are cylindrical screens on the outside of which diatomaceous earth and carbon are coated. During filtration, PCE contaminated with insolubles passes through the screen, depositing the insolubles on the outside of the screen. At the end of the day, the filter is back washed with PCE to remove the insolubles and powder sludge from the filter, and the sludge in the PCE is sent to distillation (CEPA, 1993).

Regenerative, or “bump-style,” filters are modified tubular filters that are “regenerated” after each load of clothes (CEPA, 1993). At the end of each wash load, the regenerative filter coating is

“bumped” from the filter by stopping the flow of PCE through the filter (IFI, 1994). The coating redeposits on the filter when the PCE flow is restarted before the next load.

Cartridge filters are used and discarded, while all other filter types are reusable. PCE containing insoluble impurities passes through the cartridge filter’s perforated outer shell, through paper, carbon, and a fine mesh that collectively remove the insolubles from the PCE, which then exits the filter. Several indicators may be used to determine when cartridges need to be replaced and may include pressure drop across the filter; numbers of loads or amounts of clothes cleaned using the filter. Spent filters are drained, and some drycleaners use steam to strip additional PCE from the filters. Usually, the spent filters are then removed from the facility as hazardous waste (CEPA, 1993).

The main advantage of cartridge filters is the ease and simplicity of operation and changing, requiring less labor and skill relative to other filter types, which usually require special start-up, cleaning, and handling of powder and carbon. The main disadvantage with cartridge filters is the increased hazardous waste disposal cost (IFI, 1994) and the higher loss of PCE (CEPA, 1993) relative to other filter types.

Most drycleaners use distillation to keep the solvent clean enough to avoid odors and darkening articles. Without distillation, oils, soils, dyes, detergents, and other PCE-soluble impurities would build up in the solvent. Distillation generates concentrated waste material sometimes called “still bottoms,” which contain PCE-soluble impurities. The still bottoms are often composed of 20% to 80% PCE, although steam injection or PCE/water azeotropic distillation can lower this PCE concentration to 5% in the still bottoms. The newest stills can reduce the PCE to below 1% (USEPA, 1997). Still bottoms are usually removed and treated by the same firms providing other hazardous waste disposal services to drycleaners (CEPA, 1993).

To begin the distillation process, impure PCE is pumped from the charge tank to a still. This impure PCE is boiled in a still using steam coils, and PCE vapors flow to a condenser where the PCE condenses. Two types of PCE stills are batch and flash (continuous). Condensed PCE and water flow to a water separator, that separates water from the PCE. PCE leaving the separator flows to a PCE storage tank, and in some facilities flows through a “rag” filter before entering the storage tank. Some facilities use steam or air sweeping or steam injection to remove additional PCE from the still bottoms near the end of the distillation process. At the end of this process, the still bottoms are drained before becoming cool enough to thicken (IFI, 1994).

A special type of still called a muck cooker is used with machines that use powder filters. Muck cookers have several features that stills do not: a special intake opening and valve from the filter; an agitator with a universal joint; a sight glass; and a large bottom clean out door. Muck cookers use a distillation step, then a “cook down” step, and a final air or steam sweeping step, that results in a “dry” powder muck. The “dry” muck, that contains used filter powder and other soluble and insoluble impurities from the PCE, is then removed from the cooker (IFI, 1994).

The water separator may receive PCE/water mixtures from many sources, several having been described previously: direct steam desorption of carbon adsorbers, distillation and muck cooker condensates, condensate from machines’ conventional and refrigerated condensers, and condensate from steam presses. These mixtures are received into the separator, which works using the immiscibility and

density differences of PCE and water. The mixtures enter the separator and separate into PCE and water layers, with the heavier PCE settling to the bottom. The water phase is usually drained from the top of the separator into a container for later evaporation or disposal as a hazardous waste. The PCE is usually drained from the bottom of the separator to either the PCE storage tank or the machine cylinder. The water from the separator usually contains less than 150 ppm PCE, unless the capacity of the separator is insufficient to allow proper settling time for the water and PCE phases to fully separate or the water contains detergents or other impurities (CEPA, 1993).

Wastewater Evaporation Equipment

Evaporators are used in some facilities to evaporate PCE-contaminated waste water rather than dispose of it through hazardous waste haulers or release it to the sewer. Prior to evaporation, most facilities will separate PCE from wastewater in the separator, and some facilities will pass the water through carbon for adsorption and removal of more PCE from the water. If this carbon is changed according to the manufacturer's instructions, PCE in the evaporated water can be minimized (CEPA, 1993). Vapor is vented from the evaporator to either the inside or outside of the facility. If vented inside, the PCE in this vapor will increase PCE concentrations in the facility.

Water-Repelling Equipment

Three primary methods are used to apply water-repelling or waterproofing solutions to articles. One method uses an additional storage tank, sometimes called a third tank, in which a PCE/water repellent mixture is stored. This mixture is pumped from this storage tank into the machine's cleaning cylinder, where clothes are immersed in the mixture. The mixture is then returned to the storage tank for later reuse. A second method employs hand-pumped spraying of a commercial repellent mixture (usually non-PCE based) onto articles. The third method uses a dip tank containing a PCE/water repellent mixture. Cleaned articles are placed into a wire basket that is immersed into the repellent mixture. After immersion, the basket is raised and excess liquid drips from the articles before the articles are manually transferred to a dryer.

Spill Containment

Spill containment is another control that reduces PCE losses and ground contamination due to spills. Two options for spill containment are safety troughs and floor coatings. Safety troughs are shallow rectangular tanks in which all drycleaning equipment and auxiliaries that contain solvent reside. These tanks are designed to allow for containment of the entire volume of the largest storage tank. The tank generally contains a drain that can be connected to a pump for removal of spilled solvent, or for smaller spills, rags may be used to absorb the spill and later cleaned in the drycleaning equipment. Floor coatings in conjunction with a diked area or containment lip can function similarly to a trough, although the effectiveness of these coatings has yet to be determined (CEPA, 1993).

Fugitive Emissions Control

A variety of fugitive emissions recovery, ventilation, and containment systems have been employed to reduce emissions and/or exposure to PCE vapor in the facility. The "door fan" described above under *Equipment for Vapor Recovery in the Machine* is one of these systems. Other local and

general exhaust systems may be used to remove and sometimes recover PCE vapor from air in the facility. Floor vents can be effective at removing and recovering PCE, especially in the event of spills. In some of these systems, air containing PCE can be directed to CAs to recover some of the PCE vapor (CEPA, 1993).

PCE emissions and migration within and from drycleaning facilities can also be reduced through the use of enclosures sometimes called vapor barriers. Vapor barriers can contain some or all drycleaning equipment that uses PCE and can be used to achieve minimum ventilation rates or other requirements. The walls and ceiling are made of materials that are impermeable to PCE. The enclosures have negative air pressure relative to the surrounding facility to prevent PCE migration. The air collected from the vapor barrier may be exhausted outside the facility or to a control device such as a CA to recover some of the PCE vapor (CEPA, 1993). Similarly, particular coatings and wallpapers used as PCE diffusion barriers in Germany appear to have achieved some effectiveness, although significant numbers of defective applications have been found (Hohenstein, 1994).

In facilities with transfer machines, the transfer of clothing from the washer/extractor to the dryer may result in a significant fugitive emission that does not occur in facilities with only dry-to-dry machines. Under the NESHAP, a dry-to-dry machine used in conjunction with a dryer/reclaimer is considered to be a transfer machine. Articles are damp with PCE when they are physically transferred from the washing machine to the dryer, and some evaporation occurs during this transfer. The NESHAP identifies three control technology options for reducing transfer losses: hamper enclosures, room enclosures (a particular variation of the vapor barriers described above), and replacement with dry-to-dry machines.

The most effective alternative for reducing fugitive emissions from clothing transfer is to replace the transfer machine with a dry-to-dry unit. By definition, this eliminates transfer losses, since the transfer process is eliminated. The new dry-to-dry machine would likely include process controls providing additional reductions in total PCE emissions relative to the older transfer machine. Another alternative to reduce transfer emission is to enclose the space surrounding washing and drying machines with a vapor barrier (described above) and to vent air from the enclosure to a control device, usually a CA. This alternative is sometimes called a "room enclosure." The least effective of these alternatives is a hamper enclosure, which consists of a hood or canopy that encloses the transfer basket and doors of the washer and dryer during loading and unloading and covers the hamper during movement from the washer to the dryer. The operator reaches into slits in the hamper enclosure to load and unload the PCE damp articles. A fan can draw room air into the enclosure, and air and PCE vapor are routed to a control device, usually a CA, attached to the hamper enclosure.

2.3.2 Hydrocarbon Processes Equipment

HCs were once the dominant drycleaning solvents used in the U.S. before PCE, which now predominates. The most commonly used hydrocarbons are two petroleum solvents: Stoddard solvent and 140°F solvent (IFI, 1994). However, synthetic HC and other alternatives to petroleum solvents are being marketed. Regarding the process equipment, HC equipment has not undergone the evolution that PCE machinery has, so fewer variations and options exist in HC equipment. Also, HC processes and equipment seem to have received little attention as indicated by scant coverage in literature. Therefore,

information presented in this CTSA is based on older literature sources and some more recent personal contacts.

Machine Types

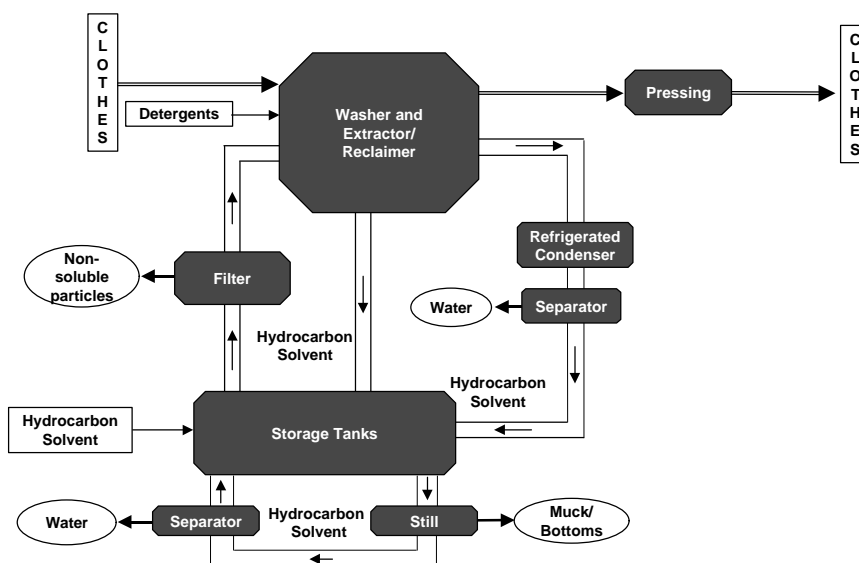
Machines used to clean garments and other articles may be classified into two types: transfer and dry-to-dry. Like home clothes washing equipment, transfer machines have a unit for washing/extracting and another unit for drying. Following HC extraction, articles that have been immersed in HC are transferred by a worker from the washer/extractor to the dryer, sometimes called a reclaimer. Dry-to-dry machines wash, extract, and dry the articles in the same cylinder in a single machine, so the articles enter and exit the machine dry. Exhibit 2-2 presents process flow diagrams for dry-to-dry and transfer machines.

Equipment for Vapor Recovery in the Machine

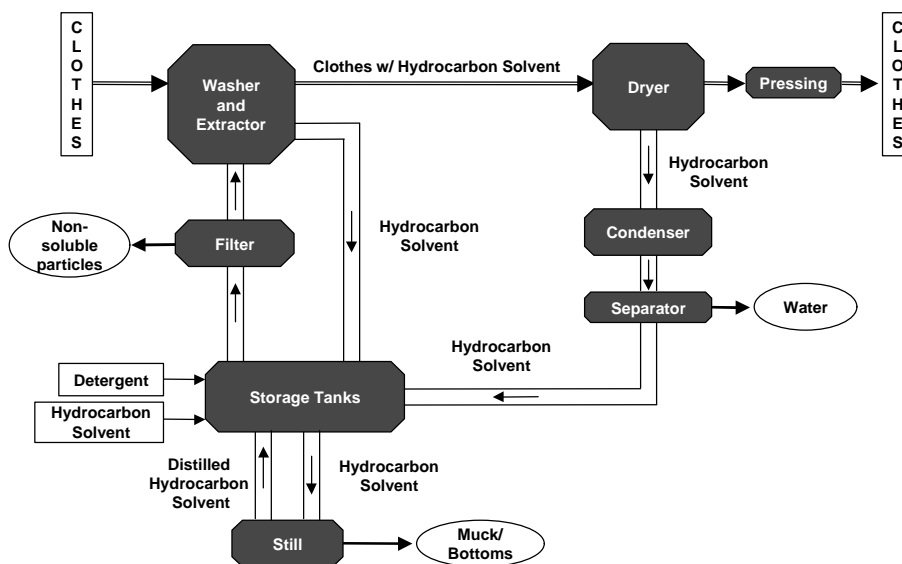
As with the PCE process equipment, HC vapor can be recovered during the drying of the articles. Some HC transfer machines have standard dryers, which do not recover any vapor during drying. Heated air is forced into the cylinder containing the wet articles, and HC vaporizes into the heated air. The heated air containing HC vapor leaves the cylinder and is then vented from the standard dryer to atmosphere.

However, machines with recovery dryers and dry-to-dry machines have condensers, which can recover HC during article drying. During the drying cycle of these machines, heated air is forced into the cylinder containing the wet articles, and HC vaporizes into the heated air. The heated air containing HC vapor leaves the cylinder, passes through a lint bag, and enters a condenser. The condenser cools the air and condenses some of the HC vapor, which is recovered. The cooled air from the condenser is reheated and cycled back to the cylinder until the condenser no longer condenses much HC from the heated air stream. For water-cooled condensers, an exhaust/cool-down cycle follows the drying cycle. In this exhaust/cool-down cycle, fresh air is forced through the tumbling clothes, removing residual HC, and is then exhausted to the atmosphere. It is not clear whether HC machines with RCs, like PCE machines with RCs, have a cool-down cycle following the drying cycle.

Two types of condensers are used to perform this HC vapor recovery: refrigerated and conventional. Conventional condensers are usually cooled using water. This cooling water may be circulated or once-through. Circulated water would pass through a cooling circuit such as a cooling tower or a water chiller. Some conventional condensers may use air for cooling rather than water.

Exhibit 2-2. Simplified Process Flow Diagram for Hydrocarbon Dry-to-Dry Solvent Machinery^a

Sources: Adapted from OTEC, Swiss Clean Hydrocarbon Drycleaning Instruction Handbook.
With consultation from Hill Jr., 1998.

Simplified Process Flow Diagram for Hydrocarbon Transfer Solvent Machinery

Source: Adapted from USEPA, 1991b for the U.S. Environmental Protection Agency's Office of Pollution Prevention and Toxics.
With consultation from Hill Jr., 1998.

^a The simplified process flow diagrams in this CTSA have been developed from various sources. These diagrams may therefore have differences in appearance, components, and flows. The reader is cautioned not to interpret all these differences as having significance due to the issues presented in this CTSA. These diagrams are intended to show some of the major equipment components and flows. Some equipment components and flows may not be shown, and some facilities may have variations which are not represented on these diagrams.

Refrigerated condensers (RCs) usually operate at lower temperatures than conventional condensers, and the lower the condenser's operating temperature, the more HC the condenser will recover from the air.

Liquid HC Reclamation Equipment

As with PCE, filtration and distillation allow drycleaners to clean and reuse HC. Careful equipment use and on-site recovery of HC reduces the amount of HC lost per volume of articles and reduces the need to purchase replacement HC. Filters remove insoluble materials from HC, and one source states that the filter options available for PCE are also available for HC (peer review comment 1-196). The four primary filter types are cartridge, tubular, disk, and regenerative. These options are discussed in detail under the *Liquid PCE Reclamation Equipment* header in the previous PCE processes equipment description section and will not be repeated here.

Most drycleaners use a distillation process to keep the solvent clean. Without distillation, oils, soils, dyes, detergents, and other HC-soluble impurities would build up in the solvent. The distillation process generates a concentrated waste material sometimes called "still bottoms" that contains HC-soluble impurities. The still bottoms normally contains a significant fraction of HC. Still bottoms are usually removed and treated by the same firms providing other hazardous waste disposal services to drycleaners (CEPA, 1993).

Vacuum stills are used to distill impure HC. The vacuum reduces the steam pressure required for HC distillation. To begin the distillation process, impure HC is pumped to a still. The steam coils in the still transfer heat to the HC, which boils, and HC vapors flow to a condenser where the HC condenses. Condensed HC and water flow to a water separator. At the end of this process, the still bottoms are drained before becoming cool enough to thicken (IFI, 1994).

The water separator may receive HC/water mixtures from several sources, some having been described previously: distillation and muck cooker condensates; condensate from machines' conventional and refrigerated condensers; and condensate from steam presses. These mixtures are received into the separator, which works using the immiscibility and density differences of HC and water. The mixtures enter the separator and separate into HC and water layers, with the heavier water settling to the bottom. The water phase is usually drained from the bottom of the separator into a container for evaporation or disposal to the sewer or as a hazardous waste. The HC decanted from the separator flows to a HC storage tank, and in some facilities flows through a "rag" filter before entering the storage tank. The water from the separator usually contains less than one part per million HC unless, as with PCE/water separation in PCE processes, the phases do not fully separate or the water contains detergents or other impurities (CEPA, 1993).

Flammability Controls

Two dry-to-dry equipment variations have been developed to reduce the likelihood of explosion by reducing the oxygen concentration in the machine. These variations are nitrogen injection and oxygen vacuum systems. No information was found in the literature for these systems. The following descriptions are based upon limited personal contacts and assumptions. The nitrogen injection and oxygen vacuum is expected to be used only during the drying cycle when air containing HC vapor is heated.

Drycleaning equipment with nitrogen injection injects nitrogen gas into the cleaning chamber in combination with HC. The addition of nitrogen lowers the concentration of oxygen, reducing the chance of explosion (Abt, 1994).

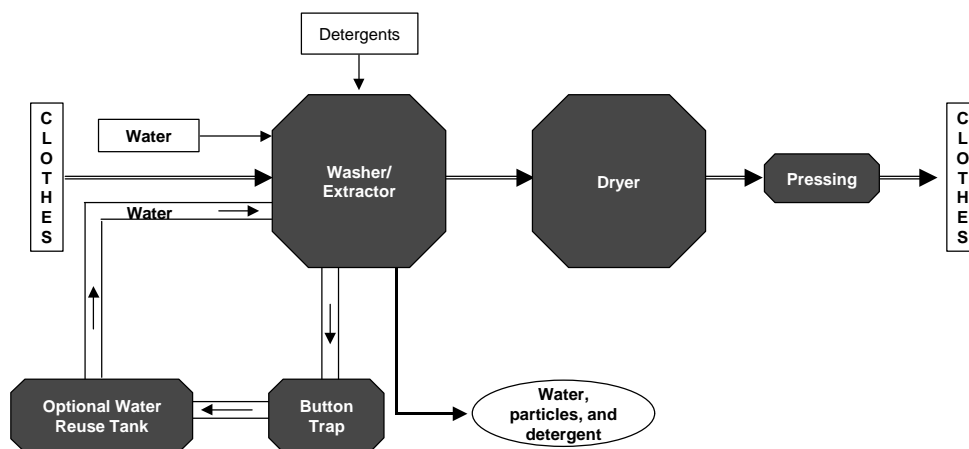
Drycleaning equipment with oxygen vacuum lowers the pressure in the cleaning chamber. The partial vacuum resulting from the reduced pressure reduces the concentration of oxygen, which greatly lowers the flashpoint of the solvent and reduces the chance of explosion (Abt, 1994).

2.3.3 Machine Wetcleaning Process Equipment

In the 1990s, several aqueous-based processes have been explored as substitutes for drycleaning of some garments. One of these processes, sometimes called “multiprocess wetcleaning,” relied heavily on hand labor to “clean” garments. This process used a variety of different techniques depending on the individual characteristics of the garment in need of cleaning. These techniques include steaming, immersion and gentle hand washing in soapy water, hand scrubbing, tumble drying, air drying. This process also used spotting and pressing as in any of the fabricare technologies. The spotter/cleaner determined which technique was most appropriate for each garment, given the fabric, construction, and degree of soiling. A number of different techniques may have been used on any one garment (Abt, 1994). Multiprocess wetcleaning has not gained acceptance as a marketable primary cleaning method. However, some of its techniques have been used to supplement the second, more widely-accepted aqueous process, which is sometimes called machine wetcleaning (Environment Canada, 1995).

The machine wetcleaning process differs from the multiprocess wetcleaning by using machinery instead of hand labor in the washing process. The basic difference in the machinery from traditional laundering units is that the agitation applied to the clothes is reduced (Abt, 1994). The following example of machine wetcleaning process equipment is particular to a Miele/Kreussler system, one of the earliest systems developed for this process. Although the equipment specifics mentioned in this section are particular to this example system, the process equipment functions for this system are expected to be generally applicable to other machine wetcleaning systems.

The example system consists of a washer/extractor and a separate dryer, which both control mechanical action and temperature (Patton et al., 1996). The principle of the system is that “spinning” clothes during both water-based washing and drying can thoroughly clean and dry the clothes without incurring the damage to delicate fabrics caused by agitation and tumbling. The washer/extractor developed for the example system has holes in its drum which have been devised to provide optimum protection for the garment being washed, and to facilitate chemical flow and active cleaning. The temperature and the water level are each monitored and controlled. The washing/extracting process is fully automated, and a liquid detergent is dispensed by two pumps at a predetermined time. After the garment washing step, the wash water containing soils, oils, and detergents is extracted and disposed to the sewer. After the garment rinsing step, rinse water may be disposed to the sewer or may be recovered and reused using storage and filtration systems (Patton et al, 1996). The dryer in the example system monitors the moisture of items in the drum, and air passes horizontally through the drum. A fraction of

Exhibit 2-3. Simplified Process Flow Diagram for Machine Wetcleaning^a

Sources: Adapted from USEPA, 1997 for the U.S. Environmental Protection Agency's Office of Pollution Prevention and Toxics. Training Curriculum for Alternative Clothes Cleaning. With consultation from Star, 1998.

^a The simplified process flow diagrams in this CTSA have been developed from various sources. These diagrams may therefore have differences in appearance, components, and flows. The reader is cautioned not to interpret all these differences as having significance due to the issues presented in this CTSA. These diagrams are intended to show some of the major equipment components and flows. Some equipment components and flows may not be shown, and some facilities may have variations which are not represented on these diagrams.

drying air is recycled, and automatic drum reversal is intended to dry the load evenly and help prevent creasing (Abt, 1994). Exhibit 2-3 shows a flow diagram of the machine wetcleaning process with a separate washer/extractor/dryer.

2.4 CHEMICAL CHARACTERIZATION OF TECHNOLOGIES

The information on hazards, releases, exposures, and risks presented in the CTSA is primarily focused upon the chemicals as they are used in the various cleaning processes evaluated. Therefore, lifecycle considerations are not a part of the CTSA. For the PCE and HC technologies, the focus is upon effects associated with those chemicals as they are used as solvents. The portrayal of risks associated with wetcleaning focuses upon the chemicals contained in the detergent formulations used. While detergents may be used in other processes, the significant reliance upon these products in wetcleaning processes warrants their evaluation under that technology. Detergent use is not evaluated for the other technologies (i.e., PCE or HC processes) because their use is less significant. Spotting chemicals are another type of chemical common to all of the cleaning technologies; however, they are not evaluated in this document.

2.4.1 Drycleaning—Solvents

Drycleaning processes utilize solvents other than water to effect cleaning. The solvents covered in the CTSA are PCE and the HCs, Stoddard solvent, 140°F solvent, and DF-2000.

2.4.2 Machine Wetcleaning—Detergents

In preparing the CTSA, USEPA collected information on wetcleaning processes' formulations through the processes' developers and machine manufacturers. USEPA received little information following the requests, and most of the information received was deemed proprietary. However, from the non-proprietary information received, USEPA developed two example wetcleaning detergent formulations. These example formulations are primarily comprised of the chemicals listed in Exhibit 2-4, and the formulations themselves are shown in Exhibit 2-5. It is important to note that it is not known how representative the formulations considered in this report will be of the potential universe of detergent formulations available. While the chemicals included are commonly found in detergent formulations, actual formulations may vary considerably in terms of both constituents and concentrations. Therefore, information presented on the individual chemical constituents of the sample formulation is presented to illustrate possible considerations associated with these types of products.

Exhibit 2-4. Example Detergent Chemicals Included in the CTSA

Chemical Name	CAS No.	Chemical Synonyms	Function
Acetic acid	64-19-7	Acetic acid glacial; vinegar; ethanoic acid	Surfactant aid
Cellulose gum	9004-32-4	Sodium carboxymethylcellulose; CMC; carboxymethylcellulose, sodium salt; CM cellulose	Surfactant
Citric acid	77-92-9	1,2,3-Propane tricarboxylic acid; 2-hydroxy-hydroxytricarballic acid	Surfactant aid
Cocamidopropyl betaine	61789-40-0	1-Propanaminium, 3-amino-N-(carboxymethyl)-N, N-dimethyl-, N-coco acyl derivatives, inner salts; cocamidopropyl dimethyl glycine	Surfactant
Ethoxylated sorbitan monodecanoate	9005-64-5	Polyoxyethylene (20) sorbitan monolaurate; sorbitan, monodecanoate, poly(oxy-1, 2-ethanediyl) derivatives	Surfactant
Lauric acid diethanolamide	120-40-1	Lauramide DEA; N,N-bis (2-hydroxyethyl) lauramide	Surfactant
Methyl 2-sulfolaurate, sodium salt	4337-75-1	Sodium methyl 2-sulfolaurate; N-lauroyl-N-methyl-taurine, sodium salt; ethanesulfonic acid, 2-[methyl (1-oxododecyl) amino]-, sodium salt	Surfactant
Sodium carbonate	497-19-8	Carbonic acid; sodium salt; soda ash; Solvay soda	Surfactant aid
Sodium citrate	68-04-2	Trisodium citrate; 1,2,3-propane tricarboxylic acid; 2-hydroxy-trisodium salt	Surfactant aid
Sodium laureth sulfate	9004-82-4	Ethoxylated sodium laureth sulfate; ethoxylated sodium lauryl ethyl sulfate; poly(oxy-1, 2-ethanediyl)-sulfo-(dodecyloxy)-, sodium salt	Surfactant
Sodium lauryl isethionate	7381-01-3	Sodium ethyl 2-sulfolaurate; sodium dodecoylisethionate; dodecanoic acid, 2-sulfoethylester, sodium salt	Surfactant

Exhibit 2-5. Example Wetcleaning Detergent Formulations

Example Detergent #1		Example Detergent #2	
Constituent	Weight Percent ^a	Constituent	Weight Percent ^a
water	54	water	54
methyl 2-sulfolaurate, sodium salt	3.75	methyl 2-sulfolaurate, sodium salt	2.14
sodium lauryl isethionate	3.75	sodium lauryl isethionate	2.14
ethoxylated sorbitan monodecanoate	7.5	lauric acid diethanolamide	4.28
lauryl polyglucose	7.5	lauryl polyglucose	4.28
Aveda's fragrance	1	sodium laureth sulfate	4.28
sodium citrate	2.5	sodium citrate	2.5
cellulose gum	5	cocamidopropyl betaine	4.28
acetic acid	5	Aveda's fragrance (orange)	1
citric acid	2.5	citric acid	2.5
diazolidinyl urea	7.5	diazolidinyl urea	4.28
		cocoamphocarboxypropionate	4.28
		sodium carbonate	10

^a Assumed based on assumed function of constituent.

Four of these chemicals, Aveda's fragrance, lauryl polyglucose, cocoamphocarboxy propionate, and diazolidinyl urea are not covered in the CTSA because information was lacking on their chemical identity.

The detergent chemicals in these example formulations can be grouped into several categories, such as surfactants and surfactant aids. Surfactants are used to reduce the surface tension of water so that it may more thoroughly wet the surface (Soap and Detergent Association, 1998) and are the primary chemicals found in the detergent formulation reviewed for this document. Surfactant aids may enhance the functions of the surfactant and can include components such as soil suspenders, pH adjusters, and solubilizers. The chemicals included as part of the machine wetcleaning detergent formulation in the CTSA are identified as either surfactants or surfactant aids.

2.5 COMMERCIAL FABRICARE INDUSTRY MARKET PROFILE

2.5.1 Introduction

The commercial fabricare industry, also called the professional clothes cleaning industry, includes approximately 36,000 facilities¹ that generate a total revenue of \$7.2 billion² annually (Seitz, 1997; Faig, 1998; Wong, 1998). Clothes cleaning volume for these facilities is estimated to be 871 billion kg (1.9 billion pounds) of clothes per year³ (Faig, 1998; Wolf, 1998). The majority (over 90%) of the 36,000 commercial fabricare facilities in the U.S. are small neighborhood stores that consist of a small storefront operation with customer pickup and delivery in the front, and cleaning and finishing in the back.

Although there are numerous fabricare processes under development, drycleaning and wetcleaning are the primary clothes cleaning processes commercially available at this time. Drycleaning uses organic solvents, such as perchloroethylene (PCE) and hydrocarbon (HC) solvents, to clean soils from clothing. HC solvents are a by-product of the distillation of petroleum and are often sold as either Stoddard solvent or 140°F solvent, in reference to its flashpoint. In 1994, Exxon introduced a synthetic HC solvent, called DF-2000, with a flashpoint above 140°F. Since then several other firms have either introduced or are testing synthetic petroleum solvents for the drycleaning market (DeSanto, 1998). Approximately 30,600 (85%) fabricare facilities in the U.S. use PCE drycleaning solvents, while approximately 5,400 (15%) use HC drycleaning solvents.

Wetcleaning is an alternative cleaning process that uses water as the primary solvent to clean fabrics. Wetcleaning is used exclusively at relatively few facilities but is used in combination with other methods at many more facilities. Exhibit 2-6 presents the solvent volume used by commercial cleaners distributed by solvent type and number of facilities. The commercial sector's total consumption of solvents is also shown.

2.5.2 Perchloroethylene Market Share and Volume

The dominance of PCE in the professional clothes cleaning market is a function of its cleaning ability for a wide range of fabrics and the materials that soil them, and its inherent fire safety advantages as compared to many hydrocarbon solvents (i.e., PCE is not a flammable liquid).

In the U.S., 37% of the PCE produced is used by drycleaners (Mannsville, 1997). Mannsville estimates that 52.6 million kg of PCE is consumed by the drycleaning industry, while Risotto places this

¹The number of facilities is estimated from data provided by the California Air Resources Board (Wong, 1998).

²Based on an average facility revenue of \$200,000 (Seitz, 1997; Faig, 1998).

³Based on \$200,000 revenue per facility and \$3/lb average revenue (Faig, 1998; Wolf, 1998).

Exhibit 2-6. Solvent Usage in the Commercial Sector of the Drycleaning Industry

Fabricare Solvent Type	PCE	HC Solvents	Wetcleaning
Number of Facilities	30,600 ^a	5,400 ^a	38 ^b
Drycleaning Volume (kg/year)	741,818,181 ^c	130,909,091 ^c	NA
Solvent Consumption (MM kg/year)	45 ^d	8.3 to 34 ^e	NA

NA = not available

^a Estimate based on 85% PCE and 15% HC use; data provided by the California Air Resources Board (Wong, 1998).

^b There are 38 facilities using wetcleaning methods exclusively (Star, 1998). By the end of 1997, 3,000 wetcleaning machines had been sold in the U.S.; however, it is not known how many facilities combine wetcleaning with other methods (USEPA, 1998).

^c Estimated from revenue (Seitz, 1997; Faig, 1998), and based on 85% PCE and 15% HC use.

^d Estimate based on Textile Care Allied Trade Association survey, adjusted for brokered import volume (Risotto, 1997).

^e Estimated from the range of mileages presented with the petroleum solvent options in Chapter 8.

estimate of consumption at 45 million kg (Risotto, 1997; Mannsville, 1997). The following three companies produce PCE in the U.S.: Dow Chemical in Plaquemine, Louisiana; PPG Industries in Lake Charles, Louisiana; and Vulcan Materials Company in Geismar, Louisiana (Chemical Marketing Reporter, 1997). In 1996 these plants produced approximately 136.4 million kg of PCE (see Exhibit 2-7) (Mannsville, 1997).

Exhibit 2-7. Total Volume of PCE (in million kg)

Year	1996
Capacity	184.9 ^a
Production	136.4 ^a
Imports	27.7 ^a
Exports	21.8 ^a
Consumption (Drycleaning)	52.6 ^b (1996) 45 ^c (1996)

^a Mannsville, 1997.

^b Based on 37% of PCE being used for drycleaning and in textile manufacturing (Mannsville, 1997).

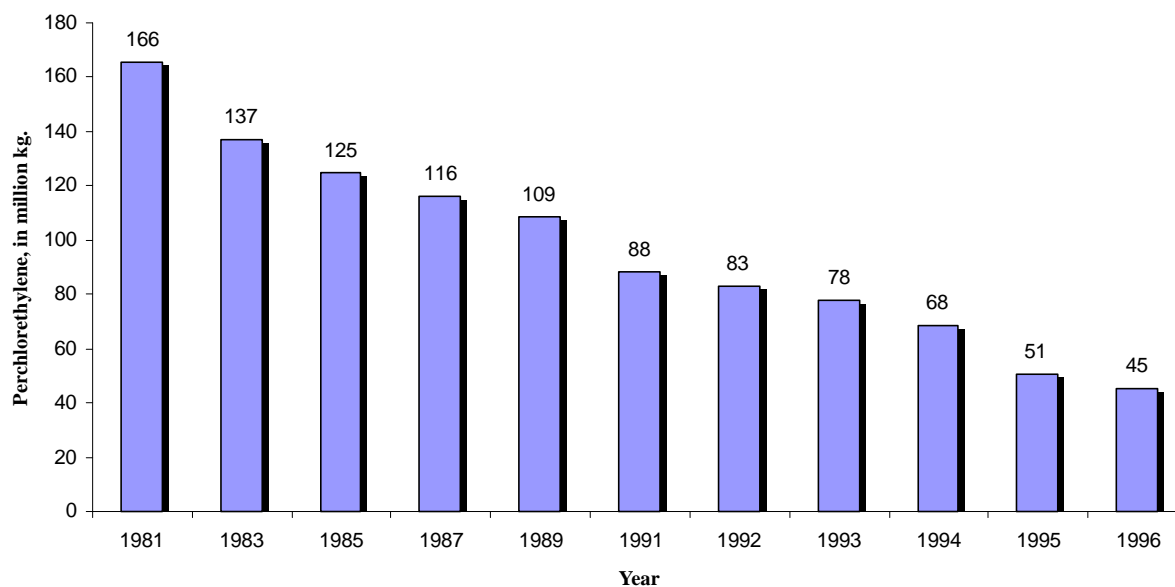
^c Risotto, 1997.

Exhibit 2-8 provides a historical perspective of PCE use in the U.S. from 1981 to 1996 (Risotto, 1997). Although PCE holds the largest market share in the clothes cleaning industry, the consumption of this chemical by fabricare facilities has clearly declined since 1981. Exhibit 2-8 demonstrates that from 1981 to 1996 there has been a 72% decrease in PCE use by the fabricare industry. One of the primary reasons for this decline is the growth in the use of wash-and-wear fabrics by the garment industry (Levine, 1997). In addition, concerns regarding the human health and environmental hazards associated with PCE have placed pressure on fabricare professionals to reduce consumption and use more benign process alternatives. Initially, the drycleaning industry has focused on designing new equipment with more effective solvent recovery and recycling systems, as well as developing safer solvent alternatives.

2.5.3 Hydrocarbon Solvents Market Share and Volume

HC solvents dominated the drycleaning industry in the United States in the 1950s. However, their use gradually declined in the next three decades, primarily due to concerns about their inherent fire and explosion hazards and the increased use of PCE by the industry. HC solvents with lower flashpoints are desirable because of their cleaning ability and quickness in drying, when compared to HCs with higher flashpoints. Increasing regulatory pressures on PCE, the introduction of HC dry-to-dry machines, and the availability of higher flashpoint solvents in the 1990s have resulted in an increase in the number of facilities using HC solvents (Baker, 1996). The proportion of establishments that rely on HC solvents for clothes cleaning is approximately 15% of all commercial drycleaners (IFI, 1989; USEPA, 1991). The Neighborhood Cleaners Association International (NCAI) predicts that the proportion of HC-using establishments has the potential to increase to almost 25% in the future if stricter regulation of PCE is implemented (Seitz, 1998)

Exhibit 2-8. Perchloroethylene Use (Domestic and Import) in the U.S. Drycleaning Industry



Source: Risotto (1997).

The current producers of HC solvent include Exxon, Ashland Chemicals Inc., Texaco Chemical Co., Plaza Group (which sells only Stoddard solvent but not exclusively to the drycleaning industry), Citgo (formerly Unocal Chemicals Division), Sun Company, Inc., Calument Lubricants, and Shell Chemicals (OPD, 1992; Hinrich, 1998; Schreiner, 1998). Besides use as drycleaning agents, HC solvents are commonly used as degreasers in manufacturing and as paint thinners (Gosselin et al., 1984). No information was available to identify the relative volumes of HC in various uses.

HC solvents used in drycleaning are differentiated as Stoddard solvent, 140°F, and Naphtha. Stoddard solvent is estimated to be used by 25% to 30% of HC drycleaners, while 140°F solvent is used by 60% to 65% of HC drycleaners (Seitz, 1998). Greater use of the latter solvent is attributed to its higher flashpoint, and therefore greater safety threshold. Naphtha solvent is estimated to be used by 10% of HC drycleaners (Seitz, 1998).

The American Society for Testing and Materials (ASTM) has developed standard specifications for Stoddard solvent that cover 10 HC solvents. These specifications are currently being revised (ASTM, 1995, Hinrich, 1998). According to ASTM, Stoddard solvents include the following four types with flashpoints of 100°F or 142°F: Type I, Full Range Mineral Spirits; Type II, High Flashpoint; Type III, Odorless; and Type IV, Low Dry Point. Each of these types contain one to three different classes with varying ranges of percent aromatic content: Class A, 8% to 22%; Class B, 2% to 8%; and Class C, 0% to 2%.

Conventional Stoddard solvents with flashpoints of 100°F to 105°F (38°C to 41°C) are highly flammable and are banned in communities with strict fire codes. Many are regulated by local air pollution control districts because of their volatile organic compound (VOC) content, which contributes to the build-up of photochemical smog. The 140°F solvent was designed to reduce the flammability and VOC problems. Due to its higher flashpoint, 140°F solvent does not require the same level of explosion-proof equipment and building construction as conventional Stoddard solvent. It is likely that the combination of new dry-to-dry hydrocarbon drycleaning equipment and the use of 140°F solvent will meet many of the fire codes that previously forced cleaners to switch to PCE (Hill, Sr., 1997).

Several of the major producers of HC solvents have recently introduced, or are about to begin marketing, products with flashpoints of 140°F to 147°F (60°C to 64°C). New equipment available to HC drycleaners and a reassessment of the drycleaning market prompted the development of these products (Exxon, 1994; Shell, 1994). The DF-2000 solvent was introduced in 1994 and is a synthetic hydrocarbon solvent with a flashpoint of 147°F. It is designed for use in petroleum drycleaning machines, such as the new dry-to-dry systems, and may also be used in PCE machines that have been properly converted (Exxon, 1998). One of the major advantages of DF-2000 is that chemical residuals are not considered hazardous wastes under the Resource Conservation and Recovery Act, (RCRA), which results in lower waste disposal costs. Manufacturers also report that pressing times associated with using DF-2000 are reduced when compared to other HC solvents (Exxon, 1998). However, DF-2000 is still a flammable liquid and is classified as a VOC. Therefore, the following restrictions may apply to this HC solvent: local fire inspectors may have to pre-approve use; waste must be transferred by a licensed hazardous waste hauling company; a permit from a local air quality management district may be required; and facilities converting to DF-2000 may be required to follow the requirements of the NFPA Code 32 (Guidelines for Class III A drycleaning plants).

In response to the increased demand for HC drycleaning machines, equipment manufacturers have added several safety features to their designs to reduce the risk of fire and explosion. For example, a new dry-to-dry HC machine may include a mechanism that injects an inert gas, such as nitrogen, into the drycleaning equipment to reduce the concentration of oxygen and thus the explosion potential. A number of systems incorporate HC monitoring equipment, which measures the HC vapor concentration and automatically shuts down the system when the solvent stream reaches the Lower Explosive Limit. Another safety method is to reduce the oxygen supply during the dry cycle by applying a vacuum and an oxygen monitor to the system to reduce the oxygen level below 8%. HC dry-to-dry machines with nitrogen injection and oxygen vacuum have been used for about 1 year in the U.S. and 4 years in Germany. There are approximately 25 HC dry-to-dry machines with nitrogen injection or oxygen vacuum in use in the U.S. (Seitz, 1998).

The market for this equipment has supported an increase from a single supplier in 1993 to at least five suppliers in 1998. Because of local fire code restrictions, each facility that purchases a hydrocarbon dry-to-dry machine must apply for a zoning variance before using the new machine. There are now approximately 250 petroleum dry-to-dry machines in use in the United States (DeSanto, 1998).

2.5.4 Machine Wetcleaning

Fabricare professionals have always cleaned a portion of their clothing throughput using domestic washers and dryers. With the introduction of more advanced washers and dryers, that incorporate microprocessor controls, the percentage of clothing that can be effectively wetcleaned is expected to increase. Other improvements that have made wetcleaning a more viable and safer clothes cleaning process include the development of specialized detergents, fabric softeners, dye setting agents that reduce bleeding, mild bleaching agents, and fabric finishes (sizing chemicals) that restore fabric hand (Seitz, undated). In the U.S., wetcleaning is being used in combination with either PCE or HC at about 200 facilities and at 38 dedicated wetcleaning shops (Star, 1998). A survey by the Hohenstein Institute of Germany reported that approximately 40% of the professional clothes cleaning stream in that country is wetcleaned, while the remaining 60% is drycleaned using PCE (Seitz, undated). While the clothing stream in Germany may differ from that in the United States, the value indicates that a greater portion of the clothing stream can be wetcleaned.

Companies selling machine wetcleaning equipment in the U.S. include Aqua Clean Systems, Inc., AquaTex, Böwe Permac, Continental Girbau (plans to market a wetcleaning machine in 1998), Daewoo Electronics Company, Edrom, Marvel Manufacturing, Pellerin Milnor Corporation, and UniMac, (Star, 1998). In addition, domestic washer models such as the Maytag Neptune have been used in facilities for wetcleaning processes. Wetcleaning chemicals manufacturers selling products in the U.S. include Adco Inc., Aqua Clean Systems, Inc., AquaTex, Büfa, Caled-Signal Corporation, Daewoo Electronics Company, EnviroSafe Wetcleaning Technologies, Fabritec International, Gurtler Chemicals Inc., Laidlaw Corporation, Priaser, R.R. Street & Co., Royaltone, and Seit (Mains, 1996; Star, 1998). The increased availability of these products (all wetcleaning chemicals were imported as recently as 1994) indicates a growing market (CNT, 1996).

2.5.5 Fabricare Industry Trends

Although PCE continues to dominate the professional fabricare industry in the U.S., the industry is undergoing significant change. Five years ago there were no hydrocarbon dry-to-dry machines or wetcleaning machines in use. Today, the major U.S. HC supplier is producing 60% HC drycleaning machines and 38 facilities perform dedicated wetcleaning. The development of alternative solvents and cleaning processes was motivated by concerns of stricter state and federal regulation of PCE, as well as increasing evidence of the chemical's negative impact on human health and the environment. In fact, many drycleaners are increasingly faced with financial liability associated with cleaning up PCE-contaminated soil and groundwater around their facilities. These concerns have made many property owners reluctant to renew leases or rent to PCE drycleaners (Lummis, 1996). In addition, several states have imposed taxes on PCE that double its price. The adoption of wetcleaning and petroleum solvents in Germany as a response to strict PCE regulation could presage the level of adoption that may occur in the U.S. However, direct comparisons among countries must be understood in the context of differences in fabric and garment type, lifestyle, geography, and climate. Different perceptions of cleaning quality among countries will also affect customer acceptance of alternative cleaning technologies.

Increasingly, fabricare professionals are proving that they can effectively wetclean many garments traditionally drycleaned. Most facilities have a washer and dryer that are being used for "wetcleaning" a larger fraction of the clothing stream than was done in 1990 (Seitz, 1995). The major challenge facing the industry is the decline in the total volume of clothing drycleaned. Several reasons have been cited for the decrease, including the increase in casual wear among office workers (Levine, 1997). The industry is addressing this by trying to broaden the services it offers to customers. For example, a cleaning facility may provide services that emphasize pressing and finishing over merely cleaning. The industry is also cooperating with clothing designers and apparel manufacturers to make professional fabricare an integrated part of the textile care process. By encouraging the use of fabrics and clothing construction compatible with professional fabricare techniques, the industry hopes to remain a viable aspect of the U.S. economy.

REFERENCES

- Abbot, T. 1998. Personal communication between Tom Abbot, Drylene, and Jessica Green, Abt Associates Inc. February 18.
- Abt. 1994. Dry cleaning industry. Use cluster analysis. Final report. Prepared for USEPA, Office of Pollution Prevention and Toxics under Contract No. 68-D2-0175. Abt Associates. April 5.
- ASTM 1995. American Society for Testing and Materials. Standard Specification for Mineral Spirits (Petroleum Spirits) (Hydrocarbon Dry Cleaning Solvent). Designation: D 235-95.
- Baker, S. 1996. Personal communication between Scott Baker, Hill Equipment Company, and Jonathan Greene, Abt Associates Inc. December.
- CEPA. 1993. California Environmental Protection Agency. Air Resources Board. Technical Support Document to the Staff Report. Proposed airborne toxic control measure and proposed environmental training program for perchloroethylene dry cleaning operation. August.
- Chemical Marketing Reporter. 1997. Chemical Profile Perchloroethylene. December 15.
- CNT. 1996. Center for Neighborhood Technology. Wetcleaning machines: a report by the Center for Neighborhood Technology obtained from the World Wide Web site <http://www.cnt.org>.
- DeSanto, Jim. 1998. Personal communication between Jim DeSanto, Marvel Manufacturing and Alice Tome, Abt Associates Inc. April.
- Environment Canada. 1995. Final Report for the Green Clean Project, Environment Canada and the Green Clean Project Participants. October.
- Exxon. 1994. Personal communication between Exxon representative and Michael Müller, Abt Associates Inc. March.
- Exxon. 1998. Information on DF-2000 downloaded from Exxon Website: <http://www.exxon.com>
- Faig, Ken. 1998. Personal communication between Ken Faig, International Fabricare Institute and Alice Tome, Abt Associates Inc. January.
- Gosselin, R.E., R.P. Smith, and H.C. Hodge. 1984. Clinical toxicology of commercial products. Williams and Wilkins.
- Hill, Sr., J. 1997. Personal communication between Jim Hill Sr., Hill Equipment Company, and Alice Tome, Abt Associates Inc. January.
- Hinrich, B. 1998. Personal communication between Bob Hinrich, Unocal, and Erica Shingara, Abt Associates Inc. April.

- Hohenstein. 1994. Summary of Research Project: Investigation of Measures for Reducing the Concentration of Solvents in the Neighborhoods of Textile Dry Cleaners. Bekleidungsphysiologisches Institut Hohenstein e.V. November 1994.
- IFI. 1989. International Fabricare Institute. Equipment and plant operations survey. Focus on Dry Cleaning. Vol 13(1). March.
- IFI. 1994. International Fabricare Institute. Drycleaning Fundamentals. A Self Study Course. October 1994.
- Levine, J. 1997. Personal communication between Jerry Levine, Neighborhood Cleaners Association International, and Alice Tome, Abt Associates Inc. January.
- Lummis, D. 1996. Personal communication between Dennis Lummis, NIE Insurance, and Alice Tome, Abt Associates Inc.
- Mains, H. 1996. Personal communication between Harold Mains, Fabritec International, and Jonathan Greene, Abt Associates Inc.
- Mannsville. 1997. Mannsville Chemical Products Corporation. Mannsville Perchloroethylene Chemical Products Synopsis. Asbury Park, NJ.
- Murphy, T. 1994. Personal communication between Tom Murphy, Kleen Rite, and Sharon Dubrow, SAIC. September.
- NIOSH. 1997. National Institute for Occupational Safety and Health. Control of Health and Safety Hazards in Commercial Dry Cleaners. March.
- OPD. 1992. 1993 OPD Chemical Buyers Directory. 80th annual ed. Schnell Publishing Co., New York, NY.
- Patton, et al., 1996. Patton, J., W. Eyring, et al. Alternative Clothes Cleaning Demonstration Shop. Final Report. Center for Neighborhood Technology. September.
- Risotto, S. 1997. Personal communication between Steve Risotto, Center for Emissions Control. and Steve Latham, Westat. December.
- Schreiner, J. 1998. Personal communication between James Schreiner, Exxon Chemical Company, and Erica Shingara, Abt Associates Inc. April.
- Seitz, W. undated. Statement by William Seitz, Neighborhood Cleaners Association. DfE conference material.
- Seitz, W. 1995. Statement by William Seitz, Neighborhood Cleaners Association, at the December 5 Phase II Stakeholders Meeting, Washington, DC.

- Seitz, W. 1997. Personal communication between William Seitz, Neighborhood Cleaners Association-International and Alice Tome, Abt Associates Inc. December.
- Seitz, W. 1998. Personal communication between William Seitz, Neighborhood Cleaners Association-International and Erica Shingara, Abt Associates Inc. April.
- Shell. 1994. Personal communication between a representative of Shell Chemicals and Michael Müller, Abt Associates Inc. March.
- Soap and Detergent Association. 1998. <http://www.sdahq.org>.
- Star, A. 1998. Personal communication between Anthony Star, Center for Neighborhood Technologies, and Erica Shingara, Abt Associates Inc. May.
- USEPA. 1991. U.S. Environmental Protection Agency. Economic impact analysis of regulatory controls in the dry cleaning industry. Final. EPA-450/3-91-021. Office of Air Quality, Planning and Standards. October.
- USEPA. 1997. U.S. Environmental Protection Agency. Cleaner Technologies Substitutes Assessment Peer Review Comments
- USEPA. 1998. Personal communication between wetcleaning equipment manufacturers and EPA.
- Wolf, K. 1998. Personal communication between Kathleen Wolf, Institute for Research and Technical Assistance and Alice Tome, Abt Associates Inc. January.
- Wong, Todd. 1998. Personal communication between Todd Wong of California Air Resources Board, and Alice Tome, Abt Associates Inc. January.